Sampling Characteristics of Vertical Towed Plankton Nets and Intercomparisons with an Optical Plankton Counter

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ABSTRACT

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The problem of calibrating optical plankton counters (OPCs) against plankton net samples for smaller copepods in the upper layers was investigated, particularly in the size range of 200-500 µm where calibration problems occur for most OPC users. This was accomplished by conducting an intercomparison of plankton nets hauls to OPC measurements and developing a methodology for intercalibrations employing a variety of sampling nets, mostly vertical haul nets and nets attached to the OPC itself. The problem of extrusion of plankton through net mesh was examined for 3 mesh sizes, 80, 140 and 202 µm, and extrusion by different species of various shapes and sizes was quantified. It was found that the narrow diameter of the oblong-shaped copepod solely governed its extrusion through the net mesh and was totally independent of its length. The most dominant species in the spring were copepod nauplii which fell into the >equivalent= OPC size range of 200-300 µm and yet less than 1/30th of their numbers were retained in the 202 µm net, thus making it less than ideal for OPC intercomparisons. It was found that the 202 µm net extruded half the zooplankton species and 80-90% of the total counts as compared to the 80 µm net.

RÉSUMÉ

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On a étudié le problème de l'étalonnage des compteurs optiques de plancton (OPC, pour *optical plankton counter*) avec des échantillons de filets à plancton pour les petits copépodes des couches supérieures. L'accent a été mis sur la fourchette de tailles de 200 à 500µm, qui pose des problèmes d'étalonnage à la plupart des utilisateurs d'OPC. Pour ce faire, on a effectué une intercomparaison des prises des filets à plancton avec les mesures enregistrées par l'OPC et mis au point une méthode d'interétalonnage recourant à divers filets d'échantillonnage, principalement des filets pour trait vertical et des filets attachés à l'OPC. Le problème d'extrusion du plancton à travers les mailles des filets a été examiné pour 3 dimensions de mailles (80, 140 et 202µm), et l'extrusion de différentes espèces de diverses formes et tailles a été quantifiée. On a constaté que la largeur des copépodes, de forme oblongue, déterminait entièrement leur extrusion, qui était totalement indépendante de la longueur des organismes. Les spécimens les plus dominants au printemps étaient des nauplii de copépodes qui tombaient dans la fourchette de tailles «équivalente» de l'OPC de 200-300µm. Pourtant, moins de1/30 du nombre de ces nauplii ont été retenus dans le filet à mailles de 202µm. Ce filet n'est donc pas du tout idéal pour les intercomparaisons avec les mesures des OPC. Il a été observé que le filet à mailles de 202µm laissait sortir la moitié des espèces de zooplancton et 80-90% des effectifs totaux comparativement au filet à mailles de 80µm.

Introduction

Intercomparison of plankton counts from an Optical Plankton Counter (OPC) and plankton nets is usually straightforward for larger size plankton >500 µm - such as *Calanus spp.* which are easily caught in 200-300 µm mesh nets where clogging and extrusion are not a problem. This is not the case for smaller size plankton such as *Clausocalanus sp.*, copepod *nauplii*, *Oithona sp.* and many others species in the size range of 200-400 µm or less. Figure 1 shows a typical size distribution measured by the OPC where one can see the major number of counts are situated in the 200-400 µm range. It is in this region of sizes that it is most difficult to compare OPC counts and plankton nets hauls.

Coupled with this issue of intercomparisons is that of plankton and plankton net terminology. For example, how does one compare OPC-measured 'ESD' (equivalent spherical diameter) with plankton mesh size? How do we relate these latter 2 parameters with 'copepod size'? Conventionally, planktologists refer to copepod size by their prosome length however we do not have a convention relating length to mesh size as a measure of 'capturability'. For example, we cannot say that a copepod with a 'size' less than a plankton mesh size will be extruded through that net. This relationship applies to spherical objects such as fish eggs, the only instance where all 3 parameters, i) ESD, ii) mesh size, and iii) organism 'size', may be equated. The object of this study is to relate these latter 3 parameters to non-spherical organisms such as copepods which have carapace length and width ratios differing by a factor of 3-5.

The earliest study of the relationship between mesh size and size of organism retention was conducted by Saville (1958). Two earlier studies (Gibbons 1939 and Wibourg 1948) characterized organism losses in plankton nets, including mesh and organism sizes but did not deduce a relationship. Saville (1958) examined the losses of organisms in a silk net which had an mesh apertures ranging from 0.221- 0.312 µm depending on whether the mesh was wet or dry and new or used. Despite the imprecise knowledge of the mesh aperture, he determined that, within the range of the above mesh sizes, the losses of organisms (i.e., *Calanus, Psuedocalanus, Microcalanus, Oithona, etc.)* could be attributed to organism widths similar to mesh size.

A more extensive study of mesh selection was conducted by Nichols and Thompson (1991) where organism losses in nets of 5 mesh sizes, 61, 90, 124, 190, 270 µm were examined for all the life stages of 3 common genera, *Calanus, Pseudocalanus and Paracalanus.* For these copepods, they clearly showed that extrusion through the net and organism losses became extremely high when the mesh size and the copepod carapace width become similar. They also recommended that a mesh size of ~75% of the copepod width is required to catch 95% of all individuals of a given size present in the seawater sampled.

In the first part of this study, net extrusion was examined for all the dominant organisms present in net catches of our Scotian Shelf waters during the Canadian GLOBEC Program. This was accomplished by measuring the dimensions of all these organisms

and comparing the catch efficiencies in nets of 3 mesh sizes, 80, 140 and 202 µm. In the second part, the ESD measured by the OPC is examined and related to a representative shape of an oblong copepod. The optimum mesh size was then determined which would allow representative intercomparison of net catches with OPC measurements. Finally a new OPC calibration representative of a 'typical' population of oblong copepod shapes was developed and used to generate abundance and biomass estimates which were then compared to net catches.

Methods

Tri-Net

Extrusion measurements were obtained by using a system of three simultaneously-mounted nets (see Figure 2) with a variety of mesh sizes. The largest mesh size (202 µm) was chosen to compare to other net samplers normally used for our programs. The remaining mesh sizes were chosen at decreasing intervals of 60 µm, that is, 140 and 80 µm mesh. The net mouth area was chosen to match that of the OPC (2 X 25 cm) while the net lengths were chosen to provide a filtering area ratio of about 25. Nets were separated by a distance of about 10 cm.

Sampling was done by vertical tows from near-bottom to surface. By vertically towing the 3 nets simultaneously and within a small area - each net would be exposed to the same plankton populations and similar integrated water volumes. Flow was not metered in the net mouths as it was concluded from previous experiments that flow could not be measured accurately within such a small mouth opening. Comparisons between nets would be made on a relative scale and net efficiency would be estimated by other methods described in the data results. The absolute net efficiency of a 202 µm mesh was the easiest to measure of the 3 nets since it was the least susceptible to clogging. This was determined from our larger net samplers (e.g. BIONESS) where water flow was metered continuously. During spring sampling conditions, the 202 µm mesh net on BIONESS towed with >90% efficiency.

Vertical Profiling OPC (VOPC)

Figure 3 shows VOPC used for vertical profiling during the program. A frame contains a Seabird CTD, a WetLabs fluorometer and a FOCAL OPC while side nets with a 20 cm mouth diameter are mounted on the outside. The side nets sample on the profile ascent while all other sensors sample in both directions. The profiling rates were maintained at 1 m/sec in both directions. Absolute plankton calibrations for the OPC were obtained during ascent by catching plankton exiting from the bottom of the tunnel into a fine mesh net (140µm & 80µm during spring & fall cruises respectively). Plankton was excluded from the tunnel and net during descent by securing a cover on the top of the tunnel and removing it by means of an acoustic release just prior to ascent. This sampling will be referred to as 'OPC calibration tows'. Clearly an 80 µm net would be the ideal choice (over the 140 µm) for minimizing plankton catch losses however there was the concern for clogging and high losses in net efficiency and so the 140 µm was chosen as a best compromise during spring. An 80 µm net was used during the fall cruise.

The cover (see Figure 3) used for isolating the top end of the tunnel had an aperture subtending an 80μm mesh net. Once submerged, it was assumed that the OPC tunnel would fill with filtered seawater reasonably free of particulates and any potential clogging of the 80 μm from the outside would not be of concern. While descending, the 80 μm net hopefully would not allow further entry of any particulates until the cover was released prior to ascent.

Other Net Samplers

Intercomparison of plankton catches was also made with other net samplers. A ring net with 0.75 m mouth diameter and 202 μm mesh was used to sample strata in the water column. Ascent rates were 0.5 m/sec. The multiple opening-closing net system BIONESS was also used enabling vertical resolution of the water column with 10 nets (202 μm mesh).

Sampling Area

Our sampling took place in eastern Scotian Shelf waters during two cruises aboard CCGS Hudson in April and October respectively. The April cruise occurred just following a spring bloom with reasonably high chlorophyll levels (3-9 mg/m^3) providing a good opportunity for net clogging. The fall cruise had typically lower chlorophyll levels of 0.5-1.0 mg/m^3. Two stations were sampled in April yielding a total of 14 Tri-net profiles and 7 OPC calibration tows. During the fall cruise, 3 stations were sampled using the Tri-net for a total of about 20 profiles and approx. 15 OPC calibration tows were made.

OPC Measurement Characteristics

Lower Detection Limit

The OPC measures the peak areal cross-section of any particle passing through its light beam. The lower detection limit of the OPC is an 'average' representation of a limit set well-above electronic noise. The digital output of '7' for example, was calibrated as the center-of-gravity matching the diameter of *Artemia* eggs of 240 μm diameter and was shown in Figure 6 of Herman (1991), where the lower limits of the measurement were seen to extend to as low as 180 μm.

The OPC detection probability distributions are shown in Figure 4 where distributions are modelled on empirical data based on calibration experiments performed in Herman (1991) and are shown for each of the digital signal output values from 6-14. The minimum detection limit was based on actual particles (spheres and copepods) dropped through the beam in water. The standard measurement error corresponding to this range is also shown in Figure 4 (percentage std. error shown in right-hand scale). As would be expected, the smallest signal has the largest error. At 240 μm the error is ± 33% while at 400 μm the error decreases to ±12%. These errors refer to those generated by the electronic/optical variations only.

Particle Biomass Estimation using the OPC

The OPC effectively measures the cross-sectional area of each particle passing through its beam. We find it useful to express this areal measurement as a diameter for

comparative purposes and this parameter is expressed as equivalent to a circle or sphere, ie. equivalent spherical diameter or esd. In converting to particle volume, the esd only works well for spherical particles such as eggs or calibration beads but introduces considerable errors for non-spherical shapes such as cylinders or oblate spheroids (egg-shapes) such as copepods. For example, consider the extreme case of an arrow-worm (cylindrical in shape) having a length-to-diameter ratio of 10:1. If we measure its area with the OPC and convert it to volume using the calibration esd, we will over estimate its volume by a factor of 3X. The body trunk of a copepod is shaped like an oblate spheroid and so having measured its cross-sectional area with the OPC, we might assume that we could 'squash' that area into the shape of a spheroid and calculate its volume. However in measuring its area we also include all its appendages which can amount to 50-75% of the body area (see Figure 5) and so we would overestimate its volume using this simple calculation. We must, in fact, separate the calculation of main copepod body and its appendages.

We take the OPC measurement of area and divide it into 2 components; 1) an oblate spheroid representing the main body of a copepod and 2) a long cylinder whose total length represents the sum of all the lengths of all the cylindrical-like appendages such as antennae, legs, tail etc. and having some average diameter representing these components. We make several assumptions regarding geometry by taking *Calanus finmarchicus* as a representative shape for copepods. Here we assume that the length-to-diameter ratio of the main spheroidal body is 4:1, the appendages represent 68% of the body area and the average diameter of the 'long cylinder' is some constant fraction of the body diameter.

The algorithm developed for calculating particle volume is presented in Appendix 1 and will be later used in calculating biomass from OPC profiles.

Zooplankton Measurements

We examined the shapes of zooplankton caught at Stns A & B, estimate their cross-sectional areas and esd and use their shape information for an analyses of net extrusion. The areal cross section of each animal was calculated by assuming a standard geometrical shape of its body trunk such as a circle, cylinder, or oblate spheriod etc. and using measured lengths (L) and widths (W). It was seen that the appendages of each animal contribute a significant area and must be calculated as well. Figure 5 shows the outline of the copepod *Calanus finmarchicus* with a trunk of an assumed shape of an oblate spheriod and where the appendages are calculated to be a 68% increase over the area of the body trunk. To simplify the process, appendage areas were calculated for one animal and a constant percentage was assumed for many species. For example all *Calanus sp.* were assumed to have a body trunk with the shape of an oblate spheroid defined by length and width and since appendages were similar in shape and number, a constant percentage of 68% was assumed. Other examples, such as nauplii, had a wider range of lengths (180-700 μm) and widths (80-320 μm) but constant a ratio of L/W (2.2:1). The appendage area was calculated for one example and the constant percentage was applied to all sizes of nauplii. Another example was *Microsetalla norvegica* which had larger L/W ratio (5.5:1) than *Calanus spp.*

The calculation of total body area and esd for all species found in our stations were made. Approximately 10-25 animals of each species were measured and a 'typical' size for each animal was selected based on the most commonly occurring sizes of each group. Nearly all species had an esd sufficiently large enough to be detected by the OPC. Nauplii however had a wide and continuous range of sizes from the smallest size of 190 X 85 µm caught in the 80 µm net, to the largest size of 730 X 300 µm caught in the larger 202 µm net. These corresponded to an esd range of 150 - 540 µm. With a minimum detection of approx. 180 µm as seen in Figure 4, it is anticipated that only a small fraction of these nauplii in the 150-180 µm range might not be counted.

Spring Cruise Results (1998)

Results from Net Hauls

On the calibration Stn A, the Tri-net was deployed from 0-70 m depth for 7 casts over a period of 1-1/2 hrs. The analyzed counts per species were summed over the 7 casts and total net counts are presented in columns 2-4 of Table I corresponding the 80, 140, 202 µm nets. Species listed were only for those having 100 counts or more. Column 1 lists species and percentage composition of total. We evaluate the ratio of counts of the 80 and 140 µm nets relative to the 202 µm net in columns 5-6. In columns 7-8 are listed the range of lengths and diameters of each species caught in the 80 µm net. Size measurements were made by microscope providing a final measurement resolution of about 20-30 µm in Table I.

Examining the columns of total net counts, we can see a clear trend of decreasing counts from the smallest mesh of 80 µm to the largest 202 µm net. The ratio of counts between the 80 & 202 µm nets (col. 5) were seen to be largest for *Microsetella norvegica* (44.8 X), *nauplii* (26.4 X), fecal pellets (10.3 X) and bivalve larvae (59.2 X) indicating considerable extrusion for these species.

We examine the relationship between extrusion and the dimensions of each species. While looking for extrusion we may be also competing with net efficiency an unknown parameter, at this point, caused by net clogging. Basically extrusion will decrease plankton catch in the larger mesh nets but net clogging will decrease plankton counts more quickly in the smaller mesh nets. In the case of extrusion, we were looking for an significant increase (say >1.5x) in counts in the 80 µm net or possibly an increase in both the 80 & 140 µm nets for a given species. Next we examine the relationship of extrusion to the length and width of various zooplankton.

Examining Table I, minimal extrusion was found for *C. glacialis*, *Centropages hamatus*, *Temora longicornis*, *Fritillaria borealis*, and *Euphausiid nauplii* where both lengths and diameters were greater than the 202 µm mesh net. *Oikopleura sp.* has an unusual shape and should be caught uniformly by all 3 meshes but many showed signs of breakage (tail from head) which may have accounted for non-uniformity of counts. Numbers for the remaining animals indicated that the 202 µm mesh and in some cases the 140 µm mesh nets were extruding animals. In the case of *Microsetella norvegica*, one saw a significant

catch in the 80 μm net and high losses in the larger meshes. Its length of 400 μm was considerably larger than all 3 meshes but the diameter of 80-120 μm favors efficient filtering in the 80 μm mesh only, accounting for the high numbers. The lowest measured diameter of 80 μm was a result of the mesh size alone and it is probable that smaller sizes exist but were not retained by the 80 μm mesh.

Nauplii had the widest range of diameters, 80-320 μm, which overlapped all 3 mesh sizes. The net counts showed large and continuous decreases from 80-140-202 μm nets. The fecal pellets also had similar diameter ranges as nauplii and exhibited similar extrusion characteristics. *Oithona similis* exhibited a definite decrease in counts in the 140, 202 μm nets. Its length of 280μm was larger than all 3 meshes but its diameter 120-240 borders on the 202 μm mesh size causing i) high losses in the 202 μm net, ii) moderate losses in the 140 μm net and, iii) efficient capture in the 80 μm net. Bivalve larvae showed significant decreases in counts in the 202 μm net. With a minimum diameter of 160 μm, there were also losses in the 140 μm net especially where these larvae are nearly spherical in shape. 'Unidentified juveniles' exhibited significant decrease in counts in the 202 μm net. With a diameter range of 160-200 μm, the maximum diameter borders on the 202 μm mesh size while the 80 & 140 μm nets should capture efficiently. *Polychaete larvae* net counts showed a continuous decrease from 80-140-202 μm nets. Its diameter ranged from 120 - 240 μm indicating increasing losses from the 140 & 202 μm nets. *Enchinoderm larvae* counts indicated significant losses in the 140 & 202 μm net and a diameter range of 120-200 μm.

The above data is strong evidence that extrusion through the plankton net mesh is governed by the narrowest dimension of each animal, that is, its diameter. For example, *Microsetella norvegica* with a diameter between 80-120 μm was caught in the 80 μm net but was clearly extruded through the mesh sizes of 140 & 202 μm. *Nauplii* had a high catch ratio (26.4) for 80/202 μm mesh (Table I). They also represent the highest catch in numbers for the 80 μm net since nauplii comprised 48% of the total. They also have the widest diameter range of 80-320 μm which would allow calculation of the net efficiency for all 3 mesh sizes.

Table II shows results from the Tri-net hauls at Stn B in Emerald Basin. Without a detailed discussion, the results from Table II show similar characteristics as Stn A in Table I. Again nauplii accounted for highest losses in numbers. It was also noted that *Microsetella norvegica* showed similar patterns of extrusion as in Stn. A. What is remarkable about this animal is the distinction between length and diameter and the clear link to diameter as the cause for extrusion. The diameter clearly lies above the 80 μm net but below the 140 & 202 μm nets while clearly exhibiting extrusion in the latter 2 nets. Extrusion was almost total in the 140 & 202 μm despite the fact that it had a length of 400 μm, much greater than all 3 nets.

Net Efficiency from Nauplii Analyses

In the absence of a measurement of flow in the Tri-nets, an analysis process was developed for determining the efficiency of the nets, in particular, to determine if any

clogging of the 80 µm net occurred. For example, let us take a hypothetical example where the 202 µm net catches, say 100 animals with diameter dimension > 202 µm, for example, *Cal. fin* stage VI. A 140 µm net should then catch more animals in total however it should also capture the same number of *CF*-VI, that is, 100. If we count only 50 *CF*-VI in the 140 µm net , then the net must be operating at 50% efficiency. We can apply the same principle to nauplii which have a wide range of sizes from 80-320 µm. If we plot the size frequency distributions for nauplii caught in 140 & 202 µm nets, the distributions should match above 202 µm provided both nets are operating at 100% efficiency.

Approximately 50 nauplii were split from each of the 3 mesh nets for 5 casts on each station and measured for length and diameter with a resolution of 20 µm. A total of 250 animals was measured for each station. Results for the frequency distribution of diameter for nauplii are shown in Figures 6-7 for Emerald Basin. Figure 6 shows the distribution for the 140 & 202 µm mesh nets. The distribution for the 202 µm net has an area of 250 counts while the distribution for 140 µm has been normalized to actual catch by using the 140/202 ratio of 2.6 from Table 2. In the region above 200 µm, the 140 µm curve falls slightly below that of the 200 µm curve. This decrease indicates a loss of counts due to a slight decrease in net efficiency which was measured at >85%.

Figure 7 shows the distribution for the 80 & 140 µm mesh nets. The 140 µm distribution has been normalized as before while the 80 µm distribution has been normalized to actual catch by multiplying by the 80/202 ratio of 6.2 from Table 2. In the region above 140 µm, the 80 µm curve falls slightly below that of the 140 µm curve. This decrease yields the same net efficiency as before measured at >85%. The diameter distribution for the 202 µm net showed that there were some numbers of animals below 200 µm ranging as low as 100 µm. Although small in number this characteristic was not seen in the 80 & 140 µm curves which decrease rapidly below their respective thresholds.

OPC Calibration Profiles - Comparison of Counts and Biomass

Calibration tows described earlier consist of catching plankton from the outflow of the OPC during the ascent of a vertical haul and comparing net counts to OPC measurements. Catches were made with a 140 µm mesh net with a filtering area ratio of 25 attached to the outflow end of the tunnel. Net samples were analyzed by microscope, counted and identified. The counts obtained were then normalized by species to the 80 µm net using the factors shown in Tables I & II. Table III lists the estimated net counts for Stn. A, tows 52-54 and Stn. B, tows 58-59 & 61-62. On average the net counts were higher on Stn A than on Stn B by about 50%. The corresponding counts from the OPC summed for each profile are presented and summed for each profile are presented in Table III. The OPC counts showed a mean decrease from Stn. A to Stn. B. In Stn. A, the OPC counts were within 50% of net counts and in Stn. B, the agreement ranged from 2% to a factor of 2X. The agreement was deemed reasonable considering the many unknowns still remaining in both sampling devices. The sample biomass was small, about 20 mg and difficult to collect. Despite the correction factor in normalizing counts from the 140 to 80 µm net, there was still unaccounted plankton extrusion occurring in the 80 µm which can be seen by the OPC. Some indications are seen and are presented in

this section. As we will see later, the variability in the net catch (numbers of animals) is consistent with the accuracy obtainable with a net.

Figure 8 shows the corresponding diameter distributions for Tows 53 and 58. Tow 53 shows higher counts at diameters of 200-300 μm while Tow 58 shows higher counts in a larger diameter range from 300- 600 μm. It is possible that some of these counts are a result of coincident counts also but are still acceptable at these animal densities. In a later section we will show that Stn. A does in fact support higher biomass consistent with its diameter distributions.

Figures 9 (a,b) show the profiles of plankton counts (per 5 m depth interval) corresponding to Stn A (Tow 53) & Stn B (Tow 58) respectively. As expected the OPC counts were greatly reduced on the descent where the OPC tunnel ends were covered by mesh. However some counts do appear as a result of plankton passing through the meshes and are counted. It was surmised that these plankton were probably nauplii or *Microsetella norvegica* with diameters slightly less than 80 μm and barely at the limit of detection by the OPC. Note the peak in counts between 20-40 m in Tow 58 which is probably sourced from the actual peak at 20 m depth (note 'up' trace) but lagged because of low flow through the tunnel on descent. In total the OPC measured very few counts on descent.

Biomass Estimates from OPC Calibration Profiles

Both Tri-net profiles and OPC calibration profiles were performed 1 hr apart on Stn A & B. We examine first the Tri-net profiles to determine variability of areal biomass at a single station over approx. a 2 hr period.

Areal biomass was calculated for all profiles of Stn A and Stn B and are presented in Table IV. Two methods of weight measurement were used by employing both GFF filters and Nucleopore membranes. A comparison of the two methods in Table IV shows slightly lower variability for the Nucleopore filters but overall both methods showed similar results. Stn.A showed higher biomass (50%) in the 80, 140, 202 μm mesh nets respectively. This would indicate higher biomass as a result of more efficient collection of smaller plankton however Stn. B showed similar biomass in all 3 mesh sizes. It was noted that with the exception of Tow 3 & 10, a comparison of the GFF filter and Nucleopore membrane data showed good agreement for the 2 methods considering the low biomass being collected and measured (100-200 mg).

Immediately following the 7 Tri-net tows at a station, the OPC was deployed for a calibration tow where OPC net captured only those animals passing through the tunnel. Biomass was calculated from the OPC calibration profiles by using the algorithm described in the section 'OPC Measurement Characteristics' and Appendix 1. Figure 10 shows the biomass profile for Tows 53 & 58. Despite the deep cast to 180, Tow 53 still had a lower biomass/m^2 overall than Tow 58 which only went to 70 m. The areal biomass was calculated for all OPC profiles in Stns A & B and are presented in Table V. The wet weights (measured using Nucleopore membranes) from each net sample are also presented. Agreement was quite reasonable on Stn A and variability was low between

wet weights and OPC measurements. The averaged biomass (gms/m^2) agreed within 10%. The variability for Stn B was higher among individual samples but was in good agreement for averaged samples.

Fall Cruise Results (1998)

Results from Tri-Net Tows

Tri-Net tows similar to those conducted (and previously described) in the spring were repeated in the fall (Oct.) 1998 on the Scotian Shelf. A total of 3 stations (C,D,E) were sampled, 2 on the Louisbourg Line (Northeast Scotian Shelf) and 1 in Emerald Basin (mid-Scotian Shelf). At Stn. C & D, 6 successive vertical tows were made in a period of 1-1/2 hrs over a depth range of 0-60m and 0-200m respectively. At Stn. E, 5 vertical tows were made over a depth range of 0-100m. Fall conditions were evident for these waters; chlorophyll concentrations were low < 1 mg/m^3 compared to spring, zooplankton species diversity was higher while zooplankton concentrations and biomass were lower.

The zooplankton data were analyzed for extrusion in a similar fashion as that made for the spring data. For each of Stn. C,D,E, the zooplankton sample concentrations for each successive tow and each of the 80, 140, & 202 μm nets, were summed and are presented in Tables VI, VII, & VIII. Rather than discuss in great detail, we can summarize results briefly here since the fall data show similar patterns as that of the spring data. By examining the net counts in Tables VI-VIII and the corresponding diameter data, we observed the following zooplankton underwent extrusion in the 140 & 202 μm nets; *Microsetella norvegica, Oithona similis, Oncaea sp., Limacina sp., nauplii,* bivalve larvae and *Conchocia spp.*. Those zooplankton captured approximately equally by all 3 nets were; *Clausocalanus furcatus, Microcalanus sp., Oithona atlantica, Paracalanus parvus, Pseudocalanus sp., Centropages typicus, and Evadne normanni*. Only *nauplii* dominated the composition on 1 station while a broader range of 4-5 species dominated the remaining samples.

OPC Calibration Profiles - Comparison of Counts

Calibration tows, similar to the spring cruise, were conducted on the fall cruise and consisted of catching plankton from th outflow of the OPC during the ascent of each vertical tow. Net counts were then compared to the OPC measurements. Based on what we learned about net extrusion from the spring cruise, we replaced the 140 μm net used in the spring, by an 80 μm net to ensure minimal extrusion and optimal capture of plankton. A total of 7 stations were sampled (stns. 17, 23, 25, 29, 36, 44, & 52) with approximately 2-3 vertical tows at each station resulting in a total of 17 tows. Collected net samples were analyzed by microscope, counted and identified. Plankton counts integrated over vertical tows were then compared to OPC measured counts and results for 17 samples are shown in Figure 11. Measured counts ranged from 100-3000. While the agreement was reasonable, it was seen that, on average, the OPC counts were lower than net counts. The 3 lowest OPC estimates (2-2.5X lower than net counts) were grouped on a single station 44 as illustrated by the data points (open triangles) in Figure11.
There are several possible reasons for the lower OPC counts. Plankton transparency is known to be more prevalent in the fall/winter and would increase non-detectability of the

smaller size animals. In these samples the dominant and smallest animals were *nauplii* and *Oithona similis*. Unfortunately this is difficult to test since preservation in formalin renders transparent animals into an opaque or blanched appearance. Many of the samples were also found to contain small jelly-like debris assumed to be derived from damaged ctenophores and salps. These are not counted during microscope analyses but are unavoidably included in the wet weight measurements. It is not anticipated that these debris are counted by the OPC due to their transparency.

OPC Calibration Profiles - Comparison Biomass Estimates

The VOPC profiles were used to calculate biomass profiles for the fall cruise. Sample profiles of biomass (g/m^3) vs. depth are shown for 2 stations in Figure12. illustrating the extreme ranges of biomass encountered. Station 20 had an areal biomass of 65.9 g/m^2 while stn. 29 had an areal biomass of only 1.0 g/m^2.

Areal biomass was calculated for the calibration profiles described in the previous section. Although the selection of stations was random throughout the Scotian Shelf, care was taken to perform the calibration tows during calm weather with minimum ship movement which may have caused net reversals. The OPC areal biomass was calculated by integrating the biomass profiles such as those shown in Figure 12. Wet weights were measured from each net sample taken from the outflow of the OPC, calculated as areal biomass (g/m^2) and then compared to the OPC measured biomass. The results from the calibration tows are presented in Figure 13. Two of the samples were eliminated from the calculation, due to the presence of large quantities of salps and jelly-like debris thereby making it difficult to separate zooplankton wet weight from that of debris wet weight.

Although the agreement and trend was reasonable over the range of 10X, it was seen that on average the plankton net biomass was higher in the low ranges of 10-30 g/m^2. As described earlier, examination of these samples indicated concentrations of jelly-like debris which would contribute significantly to the measured wet weight biomass. Unfortunately these debris cannot be easily separated from the samples during the weighing process. It is assumed however that the OPC will not detect these transparent particles and only measure the remaining zooplankton in the sample.

Comparison of Biomass Profiles: VOPC and Side-Nets

A total of 64 profiles were sampled in the spring and 52 profiles in fall using the VOPC configuration shown in Figure 3 and a comparison was made of areal biomass measurements (g/m^2) from the side net catches and the simultaneous OPC measurements. The side nets catch plankton during ascent in 2 nets, 140 and 202 µm mesh nets USED in the spring and 80 and 202 µm mesh nets used in the fall. The OPC measured profiles on both descent and ascent, in these cases the OPC plankton net and cover shown in Figure 3 were removed so the OPC could measure plankton in both directions.

In order to compare with the biomass measurements of the side-nets which collect plankton only during ascent, only the VOPC profiles on ascent were used for simultaneous comparison. The question arose as to which size net (80, 140, 202 μm) would be suitable for comparing to VOPC biomass. Although we observed large differences in plankton counts due to capture of smaller animals in the finer mesh nets, these small animals contribute little to the biomass total. Basically, 10% of the counts (ie. large *Calanus)* contribute 90% of the biomass. These differences were calculated using 2 methods. First, the OPC calibration (equation) was used to model the differences in size distributions among all 3 nets. It was estimated that the smaller plankton captured by the 80 μm net would contribute only an additional 10-20% of the total biomass as that captured by the 202 μm net.

We examined the quality of the spring data in regard to potential sample losses in nets. One major concern we had in our sampling losses was the effect of ship motion. If the nets were hauling in one direction, a rolling ship may reverse the direction of the net causing a backwash of the nets' contents. This can be easily measured by examining the CTD data corresponding the 'up' profile in which the side nets were actually collecting samples. We examined each profile estimating the 'number of reversals' that is the number of times the sampler reversed the sign of its ascent rate. We also estimated the maximum distance (m) the sampler travelled during the reversal and subsequently selected the 'peak excursion' of each profile. Both the number of reversals and peak excursion are plotted as a function of sample # (in chronological order) in Figures 14 (a,b). In sample 25, for example, we experienced 28 reversals in one profile with a peak excursion of over 5 m representing extremely rough weather conditions. For the spring cruise data, mean biomass for side net-pairs and the OPC biomass estimates for each profile are plotted in Figure 15 (a). A biomass range of 2 orders of magnitude was observed as was a mean trend of data following the 1:1 line. However, on average the data range from 10-100 g/m^2 shows the side net biomass underestimated relative to the OPC. These underestimates may be attributed to the rough weather period shown in Figures 14. To test this effect, data from profiles having peak excursions greater than 0.5 m were excluded and the remaining data were plotted in Figure 15 (b). The exclusion of data clearly improves the agreement of data indicating the potential effect of profile reversals on sample losses in nets. The discrepancies of a factor of 1-2X are consistent with the variability measured for sampling nets described in the next section 'Net Sampling Statistics'.

For the fall cruise data, mean biomass for side net-pairs and the OPC biomass estimates for each profile are plotted in Figures 16 (a). We observe that, on average, the range of biomass estimates is almost 10X lower now ranging from 1- 20 g/m^2. Although a linear trend is seen about the 1:1 line, there is again considerable scatter of data however in this data set there does not appear to be the same data bias that we observed in the spring. However, if we again apply a filter by excluding data with peak excursions >0.5 m, we observe that the scatter is reduced considerably as seen in Figure 16 (b). Again the discrepancies of a factor of 1-2X are consistent with the variability measured for sampling nets described in the next section.

Net Sampling Statistics

In Figures 15 & 16 we observed considerable scatter in the biomass estimates and could not ascertain the cause, that is, the OPC or the nets. We further analyze here the tri-net and VOPC results to determine the accuracy of net hauls with the hope of obtaining some direction in optimizing our net sampling methods. Ideally if we performed vertical tows with paired (bongo) nets with the same mouth size and obtained identical plankton counts in both nets for each zooplankton species and stages, then we would be confident that we obtained a 'representative' sample of the community in the water column that we have just sampled. We can carry the scenario one step further and allow the ship to drift 1-2 km or sample on station over a period of 1-2 hrs allowing water to advect past the station while repetitively sampling the water column 6-7 times. If we now find that the integrated plankton counts in each net were identical, we would then be confident that we obtained a ' more representative' sample of the plankton community over a 1-2 km section.

In fact we have the necessary data to test these scenarios for 'identical' counts using data from the following operations:
1) paired side nets on the VOPC (see Figure 3) - approx. 110 profiles - 2 cruises.
2) tri-nets (see Figure 2)
    i) since each net sample can be compared to the other 2- we have 3 paired net comparisons per profile.
    ii) the tri-nets were deployed 6-7 times on each of 5 stations (2 cruises) - enabling us to test the 'more representative' 1-2 km section.

We begin by listing the 3 main sources of variability which might deteriorate the measurement accuracy of our net measurements:

1) Spatial Variability
Spatial scales of high plankton variability may occur at 1-2 m or less, corresponding to the separation of the net pairs.

2) Sampled Volumes
The selection of net mouth area is related to spatial scales, generally the higher the sampled water volume, the better our sampling statistics for low abundance plankton. Yet we still do not know what these spatial scales are nor the appropriate net mouth area.

3) Sample Splitting Procedures
This process requires a uniform distribution of plankton throughout the sample volume to ensure a uniform and equal split. Generally, the higher concentrations of animals are expected to split more uniformly, e.g. splitting 2 animals evenly is far more difficult than splitting 100 animals evenly. Finally we do not know the number of animals required in a split which would be 'representative'.

We examine these sources of variability by examining our data results and subsequently eliminating these sources. We begin with the premise that each of the plankton species

and stages should be caught in equal numbers in each of the net pairs, i.e. there should be the same number of *Calanus finmarchicus* V in each net pair. Since we are comparing nets with different mesh sizes, we exclude all those animals that would be extruded through the largest mesh. We set the criteria that includes only those animals with their diameter (carapace width)>220 µm, thereby only those that would be caught by a 202 µm mesh, the largest of the 3 mesh sizes. When present in our samples, these would include *Calanus finmarchicus I-VI, Calanus glacialis I-VI , Calanus hyperboreus I-VI, Centropages typicus III-VI, Paracalanus parvus V-VI, Pseudocalanus sp.V-VI, Centropages hamatus V-VI, Temora longicornis V-VI, Fritillaria borealis, Evadne normanni,* and *euphausiid nauplii.*

We calculate the ratio of plankton counts of the net pair as the 'higher counts' divided by the 'lower counts' thereby calculating the absolute difference-ratio between any pair of nets. Therefore a ratio of 1.00 ideally indicates the plankton counts in each net pair to be identical while a ratio of 1.30 indicates a difference of 30%. We begin with the VOPC side-net pairs for the spring cruise and calculate ratios for all the above species including those plankton where there is 1 count or more in the split. Having applied all the above criteria, there were remaining 160 net pair samples for which we calculated ratios for each of the net pairs. By averaging, we calculated a mean ratio of 2.3 indicating that the average agreement between the net pair is a factor of 2.3X.

We then examined the effect on the mean ratio by setting a limit on the minimum number of counts per split, that is, if the minimum limit were set at 5 counts, then must be a minimum of 5 animals of a specific species and stage, i.e. *Cal. fin. II* or *Cal. glacialis IV* in that split for the data to be included. This will, of course, decrease the number of samples available to calculate the mean ratio but will improve the counts statistics per species. With a min. counts per split of '1 ' there were 160 samples, with 10 counts - 40 samples, and with 60 counts - 1 sample. The plot of mean ratio versus the minimum number of counts per split is presented in Figure 17, referring to the curve 'VOPC Net Pairs'. The results showed a slight but smooth decrease in the ratio from split counts 1-10 while the data showed higher fluctuations between split counts 10-60 due to a rapid decrease in the number of samples. Based on achieving an ideal ratio of 1.00, the results indicate that there is no significant improvement with an increase in split counts ranging from a single animal per split to a supposedly large number (60) of animals per split. The optimal 'uncertainty' we can expect from these net measurements is a factor of 2X.

We then performed a similar calculation for the Tri-net data obtained in the spring cruise. Sampling consisted of 7 vertical tows per station on 2 stations. Each tow with 3 nets side-by-side however represents 3 net pairs. The calculations of mean ratios using the same criteria as above was performed and is shown by the curve 'Tri-Net Pairs' in Figure 17 plotted against 'min. # of plankton in split'. Essentially the results, ranging from 2.0-2.6, were similar to those of the VOPC side-nets. This was also a surprising result since the Tri-Nets represent a decrease in net mouth area (and therefore water volume) by a factor of 6X and yet there was no deterioration in sampling variability.

We then examined the Tri-net data per station having performed 7 successive vertical tows on each of 2 stations in a period of 1-1.5 hours. For each plankton species and stages and for each net, the counts were added together from all 7 samples. The effect therefore is to examine the integrated counts of 1 net deployed 7 times on the same station and compare it to the other 2 nets. The min. split counts now represents the sum of the 7 splits for a given species and stage. Overall, the number of samples, used to calculate the mean ratio, will now decrease. At a min. split counts of '1' there were 35 samples, at 10 counts - 12 samples, and at 170 counts - 1 sample. The mean ratio as a function of min. counts split is shown in Figure 17 indicated by the 2 curves (2 stns.) labelled 'Summed Pairs'. The results show that at split counts of 7 or greater, the ratio is consistently < 1.2 indicated a dramatic improvement in sampling variability. Moreover by adding the 7 tows, we have only increased the total volume sampled by an amount equivalent to that volume sampled by the VOPC side-nets. Essentially, for a single vertical tow on a station, we might expect an uncertainty in abundance measurements of 2-2.5X whereas by sampling the same volume over 7 tows in 1-1.5 hours, we might expect an uncertainty of only 20%.

We repeated a similar analyses on the fall data. For 3 Tri-net stations and 5-6 successive profiles in a 1-1.5 hour period, the mean ratio for Tri-net pairs ranged from 1.7-2.1 while summed pairs yielded a mean ratio of 1.25. The VOPC net pairs were not calculated as plankton identification of samples was not made due to cost. Fall results therefore were essentially comparable to spring results.

From these results, we would conclude that a single vertical net tow (at least in our particular net design) carries an uncertainty of a factor of 2X in measuring the abundance of a single species which does not appear to be dependent of the size of net (water volume sampled) or the size of split taken. This gives us some insight into the sources of variability encountered in comparing OPC results with nets, e.g. biomass estimates shown in Figures 15 & 16. Our largest variability occurs at scales of several meters while reduction of the sampling variability requires sampling over broader spatial scales.

DISCUSSION

The OPC can produce reasonable estimates of plankton counts and biomass from vertical hauls using relatively simple profiling platforms such as the one shown in Figure 3. Other examples are the US CALCOFI Program which currently uses, as a standard sampling tool, an OPC integrated with BONGO nets. Vertical zooplankton hauls are relatively quick and practical methods of obtaining zooplankton information and, coupled with the OPC, can provide additional information on the vertical location of size groups and potentially species identification. It is important that both measurements of OPC and net sampling are made simultaneously however it is not clear that one is more accurate than the other but they are in fact complementary. It would be desirable to have better agreement between OPC and nets tows as that which was demonstrated in Figures 15 & 16, however it was also clear that our nets produced some inherent variability of a factor of 2X.

It was our observation in past sampling that OPC counts are typically higher than corresponding plankton counts in nets of mesh size 202 µm. It was the observation of this study that plankton densities are normally undersampled due to the chronic problem of losses of plankton during either the sampling or handling process. The major cause of sampling losses are extrusion of small plankton through net mesh. Losses in plankton numbers were high - typically ranging over a factor of up to 100X. Another possibility for major losses was net profile reversal in rough weather causing a backwash or 'pumping' of nets while resulting in losses of up 90% of the sample. In fact tests on subsequent cruises have borne this out and these data will be reported in a future paper. Losses in this case are uniform across all sizes of plankton and are directly proportional in loss of biomass and counts. The effect is most pronounced in vertical net hauls since the pitch and roll of the ship is directly transferred to a net but can be equally effective in towed nets with steep cable angles as well. Presumably a reversal is more serious at the end of tow, say, in the upper layers before the net breaks surface, at which time the net contains (and may lose) its maximum load.

The narrow diameter of an oblong copepod governs its extrusion through net mesh while the length of an animal appears to play little role in its retention. *Microsetella norvegica* illustrated this best where its length was larger than any of the 3 mesh sizes but was extruded through the 140 and 202 nets. With a diameter between the 80 and 120 µm nets, it was caught only by the 80 µm net. As a result, the 202 coarse mesh net caught only about 10% of the plankton population by number representing a loss of about two-thirds of the species present. Although this may represent only a small loss in biomass, perhaps 10-20%, it certainly would not adequately represent a plankton population and its density.

The choice of sampling mesh can only be defined by one's sampling needs. One conventional guideline is that it is dependent on whether one wishes to sample mesozooplankton vs microzooplankton. But how do we define the size limits of either and to what does that 'size' refer, eg., length, or diameter, or a mean of the two? Finally how do we relate that 'size' to mesh size? One often uses the copepod length as defining copepod 'size' but clearly this has no bearing on 'capturability' by a net. If it proves true that we can only relate 'capturability' by net of a given mesh size to the narrow diameter of a copepod, than perhaps we should begin to define 'size' as that dimension of an animal which only can be related the mesh size.
If the goal in our climate monitoring programs is assess and study community composition, then the 80 u net would be an optimum choice for representative sampling and would be the maximum size recommended for collecting plankton that are detectable by, and comparable to, the OPC. The operating efficiency of the 80 µm net (>85%) was quite reasonable for our spring post-bloom sampling conditions with high chlorophyll levels of 3-6 mg/m^3. In this respect, vertical hauls in our sampling were ideal for maintaining 'clean' nets. Our VOPC side nets had a filtering area ratio of 25 and were hauled through vertical distances of 100-200 m from bottom to surface. Any clogging that occurred would take place in the surface layer or the last 30-40 meters of the vertical haul. Oblique or horizontal tows over the same depth of 100 m would traverse greater distances and may increase the potential for net clogging.

The high operating efficiency of our 80 µm net may be simply specific to our region and conditions. It may not be adequate during our spring bloom period where chlorophyll conc. exceed 10 mg/m^3. Different species of phytoplankton in other regions may affect clogging rates differently and would have to be tested. Ideally we will continue to operate the VOPC profiler with side nets of 80 and 202 µm mesh nets and over time we may be able to determine the utility of the pair.

From these observations, it was estimated that our plankton nets deployed on single vertical hauls could not deliver measurement accuracies for plankton counts or areal biomass better than a factor of 2X. The magnitude of these measurement errors may not be problematic in some studies considering the significance of the range of areal biomass encountered from about 1-100 gm/m^2 or about 2 orders of magnitude. For example, a change in biomass that might be considered significant would be a change of a factor of 5X as we might observe over different regions or seasonally.

Despite the smaller size of our tri-net, within the scenario we used, it is capable of delivering 'accuracies' of 20%. We estimate that during the 1-1.5 hour sampling of 7 successive tri-net tows represented sampling along a 1-3 km section as a result of advection (measured by ADCP) past our ship 'on station'. It may be reasonable to envisage a scenario where, say, a small cylindrical net of 8-10 cm in diameter, could be cycled while the host vessel made minimum headway at 2-3 kts. The net would sample continuously on ascent but be choked on descent. Logistically, of course, this would increase demands on shiptime.

For the plankton populations we are measuring, e.g. *Calanus* spp. (2-3 mm) and smaller, we can achieve measurement accuracies of 20% using a specific sampling protocol. Using a small cylindrical plankton net with a mouth opening of 8-10 cm, 3 m in length and cycling 6-7 times over a 1-2 km line as described in the previous Section, measurement accuracies of 20% can be achieved.

The OPC measures biomass and counts reasonably well despite its small sampling volume (compared to nets) possibly because it is not subject to the same degree of sample losses as plankton nets. In high plankton densities of >70,000 m^{-3}, the OPC (with an acrylic insert) will not measure plankton counts accurately because of coincidence counts, that is, 2 or more animals in the beam simultaneously will be counted as one. By the same token, the OPC will 'sum' the coincident particles and measure the total biomass with reasonable accuracy.

During spring, the OPC still overestimated the biomass relative to net measurements. This may be due to persistent and unaccounted losses of plankton in nets but may also still be a result of the model calibration chosen for the OPC which is radius sensitive to population composition. Over time and sampling intercomparisons, the calibration should improve.

Our estimates indicate a low probability of detection of phytoplankton of the largest species *Ceratium longipes* and *Thalassiosira sp.* present during our post spring bloom conditions. That is not to say that there could be conditions which could result in phytoplankton detection, for example, a narrow and high-density peak with sharp gradients. For the most part the dominant diatoms of <10-20 μm formed the light attenuance continuum or background which was not detected by the OPC. The OPC is designed to compensate for light attenuance changes in its environment.

Evidence indicates that marine snow in our region is not detectable by the OPC and suggests that it is either broken up in the turbulence of the tunnel and/or is not optically detectable by the OPC. There may of course exist varieties of marine snow that could be easily detectable and would have to be investigated on a regional basis.

The VOPC sampler shown in Figure 3 is a compact system and is rapidly deployed. Once immersed, the sampler can be lowered and raised in several minutes. The configuration used for OPC calibration shown in Figure 3 is simple, effective and reasonably accurate. In comparing OPC and plankton net catches from the tunnel outflow, extreme care must be exercised in sampling handling. The potential for error is large since one is handling wet weights that are <1/1000 of typical catches or as little as 10 mg. The thorough 'washing down' of nets prior to removal of cod end is critical to ensure collection of total catch.

The OPC and these small plankton nets may not perform well in capturing or providing adequate statistical sampling of animals larger than *Calanus spp.*. We have encountered many problems with catches containing larger animals such as juvenile euphausiids, for example, which are capable of avoiding the OPC but may be captured in the larger side nets. We have seen numbers of juvenile euphausiids in the side nets but not measured by the OPC even though their signal should be easily detected optically. From a statistical argument alone, larger animals of low abundance may simply be captured by a larger size net and perhaps not by the OPC. The presence of even a few of these animals can result in wet weights 10X higher than that of the OPC estimates. Some criteria therefore must be applied in selecting an upper limit of 'cut-off' size excluding these larger size animals in both the weighing process and the OPC estimates. We have selected *Calanus spp.* as an upper limit for species while excluding, for example, euphausiids, salps, Ctenophores, and arrow worms .

Use of the acrylic insert in the OPC tunnel to reduce volume appears to be necessary during spring in our region as plankton numbers are higher and coincidence more prevalent. During fall in our shelf waters, the numbers are reduced sufficiently to allow removal of the acrylic insert while maximizing statistical counts.

APPENDIX 1

We develop here the algorithm for calculation of volume from OPC measurements. The measurement of area made by the OPC is divided into 2 components: 1) the oblate spheroidal shape of the copepod body and 2) a long cylinder with a length representing the sum of all the component appendages of a constant diameter. Geometry of the 'reference' copepod *Calanus finmarchicus* is used.

Rat = 4 - length-to-diameter ratio of the oblate spheroidal copepod body

Fra = 0.68 - the fractional area of the appendages relative to the (spheroidal) body area.

Frd = 0.12 - fraction of the 'long cylinder' diameter to the diameter (minor axis) of the spheroidal body.

RDS= Raw Digital Size (from OPC)

Diameter:

$d= 154.1516+9.0567 \times RDS-0.016177 \times (RDS)^2 +0.0000110664 \times (RDS)^3$ (range 0-3000 µm max.)

Radius in cms:

$r=d/(2 \times 10000)$

Oblate Spheroid

Spheroid radius (semi-minor axis)

$SR= (\pi r^2 / (\pi \times Rat \times (1+Fra)))^{1/2}$

Spheroid Length (semi-major axis):

$SL= Rat \times SR$

Spheroid Volume:

$SV= 4\pi/3 \times SL \times SR^2$

Cylinder

Cylinder Area - (cross sectional area - longitudinal)

$CA = \pi r^2 /(1 + 1/Rat)$

Cylinder Diameter

$CR = Frd \times SR \times 2$

Cylinder Length

$CL = CA/CR$

Cylinder Volume

$CV = \pi \times (CR/2)^2 \times CL$

Total Volume (cc) = (Spheroid Vol.) + (Cylinder Vol.) = SV + CV

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TABLE I - Spring Cruise Stn A								
Species	Total Net Counts			Ratio	Ratio		Length	Diameter
>100 counts	80 µm	140 µm	202 µm	80 / 202	140 / 202		µm	µm
C. glacialis I (0.3%)	192	174	188	1.0	0.9		950-1000	240-280
Centropages hamatus (V-VI) (1%)	576	684	666	0.9	1.0		800-1200	280-400
Microsetella norvegica (1%)	358	16	8	44.8	2.0		400-440	80-120
Oithona similis (0.6%)	4226	3736	1506	2.8	2.5		280-480	120-240
Pseudocalanus sp.(V-VI) (4.7%)	2686	2200	2088	1.3	1.1		700-	320-400
Temora longicornis (V-VI) (1.1%)	640	870	684	0.9	1.3		800-920	240-400
unidentified juvenile (1.0%)	594	824	180	3.3	4.6		400-480	160-200
nauplii (48.1%)	28498	8338	1078	26.4	7.7		190-700	80-320
fecal pellets (26.6%)	15740	8052	1522	10.3	5.3		360-640	80-200
Fritillaria borealis (1.6%)	920	734	808	1.1	0.9		>800	>300
Oikopleura sp. (1.4%)	818	628	438	1.9	1.4		>1300	>400
bivalve larvae (1.8%)	1066	416	18	59.2	23.1		160-200	160-200
polychaete larvae (2.2%)	1308	442	182	7.2	2.4		400-880	120-240
euphausiid nauplii (0.2%)	138	210	144	1.0	1.5		440-560	240-280
echinoderm larvae (0.6%)	358	158	100	3.6	1.6		440-520	120-200

Table I. Total counts of zooplankton sampled in the Tri-Net vertical hauls on Stn. A during the spring cruise. The counts are presented for the three nets of mesh sizes, 80, 140 & 202 µm. Viewing the counts from 80 to 202 µm, one can see significant decrease or losses in the larger mesh, particularly nauplii and *Microsetella norvegic.*

TABLE II - Spring Cruise Stn. B								
Species	Total Net Counts			Ratio	Ratio		Length	Diameter
>100 counts	80 µm	140 µm	202 µm	80 / 202	140 / 202		µm	µm
C. finmarchicus I (0.8%)	332	224	300	1.1	0.7		680-720	200-240
Microsetella norvegica (4.5%)	1864	104	312	6.0	0.3		400-440	80-120
Oithona similis (16.5%)	6704	6744	4684	1.4	1.4		280-480	120-240
Pseudocalanus sp. (V-VI) (3.5%)	1416	1448	1372	1.0	1.1		700-1100	320-400
unidentified juvenile (2.3%)	1032	1504	588	2.3	2.6		444-480	120-160
damaged (0.5%)	200	368	152	1.3	2.4		440-480	120-160
egg (0.4%)	176	104	116	1.5	0.9		350-500	140-280
nauplii (56.9%)	23104	9608	3712	6.2	2.6		190-700	80-320
fecal pellets (0.3)%	108	40	84	1.3	0.5		360-640	80-200
Fritillaria borealis (3.8%)	1544	1808	1892	0.8	1.0		>800	>300
Oikopleura sp. (0.2%)	92	144	168	0.5	0.9		>1300	>400
bivalve larvae (2.9%)	1168	1106	112	10.4	9.9		160-200	160-200
polychaete larvae (3.6%)	1452	536	592	2.5	0.9		400-520	120-240
euphausiid nauplii (1.3%)	532	584	512	1.0	1.1		440-560	240-280
echinoderm larvae (0.7%)	284	72	124	2.3	0.6		440-520	120-200

Table II. Total counts of zooplankton sampled in the Tri-Net vertical hauls on Stn. B during the spring cruise. The counts are presented for the three nets of mesh sizes, 80, 140 & 202 µm. One can see significant decrease or losses in the larger mesh, particularly nauplii and bivalve larvae.

TABLE III
Comparison 0f Net Counts and OPC Counts

	NET COUNTS	OPC COUNTS
STN A		
Tow 52	5665	3445
Tow 53	2744	3553
Tow 54	2549	3507
STN B		
Tow 58	2640	3512
Tow 59	1770	3440
Tow 61	2504	2458
Tow 62	1194	2038

Table III. Comparison of OPC measured zooplankton counts and counts measured from a net attached outflow of the OPC. Three stations were measured on Stn. A and four were measured on Stn. B.

TABLE IV
SPRING CRUISE - TRI-NET BIOMASS
Wet Weight (gms/m²)

STN A	GFF Filters			Nucleopore Membranes		
Net Mesh µm	80	140	202	80	140	202
Tow 3	22.0	6.0	8.0	11.1	8.5	8.4
Tow 4	40.0	28.0	26.0	58.3	39.3	38.4
Tow 5	52.0	82.0	40.0	67.6	81.9	59.0
Tow 6	34.0	28.0	18.0	45.6	43.3	37.7
Tow 7	50.0	34.0	34.0	46.7	50.3	42.2
Tow 8		48.0	38.0		47.8	37.4
Tow 9	72.0	24.0	20.0	64.6	48.1	36.7
Avg	45.0	35.7	26.3	58.8	45.6	37.1
	Stn A Avg =		35.7	Stn A Avg =		47.2
STN B						
Tow 10	12.0	20.0	20.0	7.4	12.2	18.1
Tow 11	26.0	18.0	18.0	23.6	15.7	10.0
Tow 12	16.0	14.0	16.0	16.4	22.3	25.6
Tow 13	30.0	22.0	20.0	18.3	11.9	17.1
Tow 14	32.0	36.0	28.0	24.6	23.0	28.5
Tow 15	32.0	32.0	38.0	38.3	35.7	32.1
Tow 16	34.0	26.0	56.0	32.8	25.0	58.5
Avg	26.0	28.0	32.7	23.1	20.8	27.1
	Stn B Avg =		28.9	Stn B Avg =		23.7

Table IV. Comparison of methods of measuring biomass of net samples using GFF and Nucleopore filters from 7 vertical tows on Stns. A & B.

TABLE V
OPC CALIBRATION TOWS - Spring Cruise
Wet Weights - 140 µm Net

	Wet Wts (gms)		OPC Measured	
STN A				
Tow 52	60		55.3	
Tow 53	50		59	
Tow 54	38.4		50.9	
	Stn A Avg = 49.5		Stn A Avg = 55.1	
STN B				
Tow 58	23.2		36.8	
Tow 59	24.8		43.6	
Tow 61	35.6		20	
Tow 62	25.6		16.8	
	Stn B Avg = 27.3		Stn B Avg = 29.3	

Table V. Comparison of biomass measurements made by the OPC and from net counts measured from the OPC outflow.

TABLE VI - Fall Cruise Stn C

Species	Total Net Counts			Ratio	Ratio		Length	Diameter
	80 µm	140 µm	202 µm	80 / 202	140/ 202		µm	µm
Centropages typicus (iii-vi)	1526	1098	1344	1.1	0.8		440-1120	220-420
Microsetella norvegica	2356	93	16	147.3	5.8		400-440	80-120
Oithona similis	1428	902	624	2.3	1.4		280-480	120-240
Oncaea sp.	72	13	2	36.0	6.5		220-400	120-160
Paracalanus parvus (v-vi)	442	373	526	0.8	0.7		580-760	220-280
Pseudocalanus sp. (v-vi)	240	168	178	1.3	0.9		580-760	200-300
nauplii	498	57	10	49.8	5.7		190-700	80-320
bivalve larvae	208	129	38	5.5	3.4		160-200	160-200
Evadne nordmanni	102	89	80	1.3	1.1		720-960	400-600

Table VI. Total counts of zooplankton sampled in the Tri-Net vertical hauls on Stn. C during the fall cruise. The counts are presented for the three nets of mesh sizes, 80, 140 & 202 µm. One can see significant decrease or losses in the larger mesh, particularly nauplii and *Oithona similis*.

TABLE VII - Fall Cruise Stn D

Species	Total Net Counts			Ratio	Ratio		Length	Diameter
>100 counts	80 µm	140 µm	202 µm	80 / 202	140 / 202		µm	µm
Centropages typicus (v-vi)	390	326	306	1.3	1.1		440-1120	220-420
Microsetella norvegica	1556	62	10	155.6	6.2		400-440	80-120
Oithona similis	3260	2630	1892	1.7	1.4		280-480	120-240
Paracalanus parvus (v-vi)	594	572	640	0.9	0.9		580-760	220-280
nauplii	3588	238	18	199.3	13.2		190-700	80-320
bivalve larvae	100	102	34	2.9	2.9		160-200	160-200

Table VII. Total counts of zooplankton sampled in the Tri-Net vertical hauls on Stn. D during the fall cruise. The counts are presented for the three nets of mesh sizes, 80, 140 & 202 µm. One can see significant decrease or losses in the larger mesh, particularly nauplii, *Oithona similis* & *Microsetella norvegica*.

TABLE VIII

Species	Total Net Counts			Ratio	Ratio		Length	Diameter
>100 counts	80 µm	140 µm	202 µm	80 / 202	140 / 202		µm	µm
Clausocal. furcatus (v-vi)	240	192	184	1.3	1.0		580-780	240-300
Microcalanus sp.	200	364	212	0.6	1.2		360-480	180-240
Microsetella norvegica	1104	84	152	7.3	0.6		400-440	80-120
Oithona atlantica (v-vi)	144	152	128	1.1	1.2		360-560	120-220
Oithona similis	6008	4376	2312	2.6	1.9		280-480	120-240
Oncaea sp.	2968	84	36	82.4	2.3		220-400	120-160
Paracalanus parvus (v-vi)	1472	1012	1168	1.3	0.9		580-760	220-280
nauplii	12504	512	132	94.7	3.9		190-700	80-320
Oikopleura sp.	240	220	132	1.8	1.7		>1300	>400
Limacina sp.	712	568	48	14.8	11.8		140-320	100-180
Conchoecia spp.	112	136	56	2.0	2.4		300-896	200-480

Table VIII. Total counts of zooplankton sampled in the Tri-Net vertical hauls on Stn. E during the fall cruise. The counts are presented for the three nets of mesh sizes, 80, 140 & 202 µm. One can see significant decrease or losses in the larger mesh, particularly nauplii, *Oithona similis* & *Microsetella norvegica*.

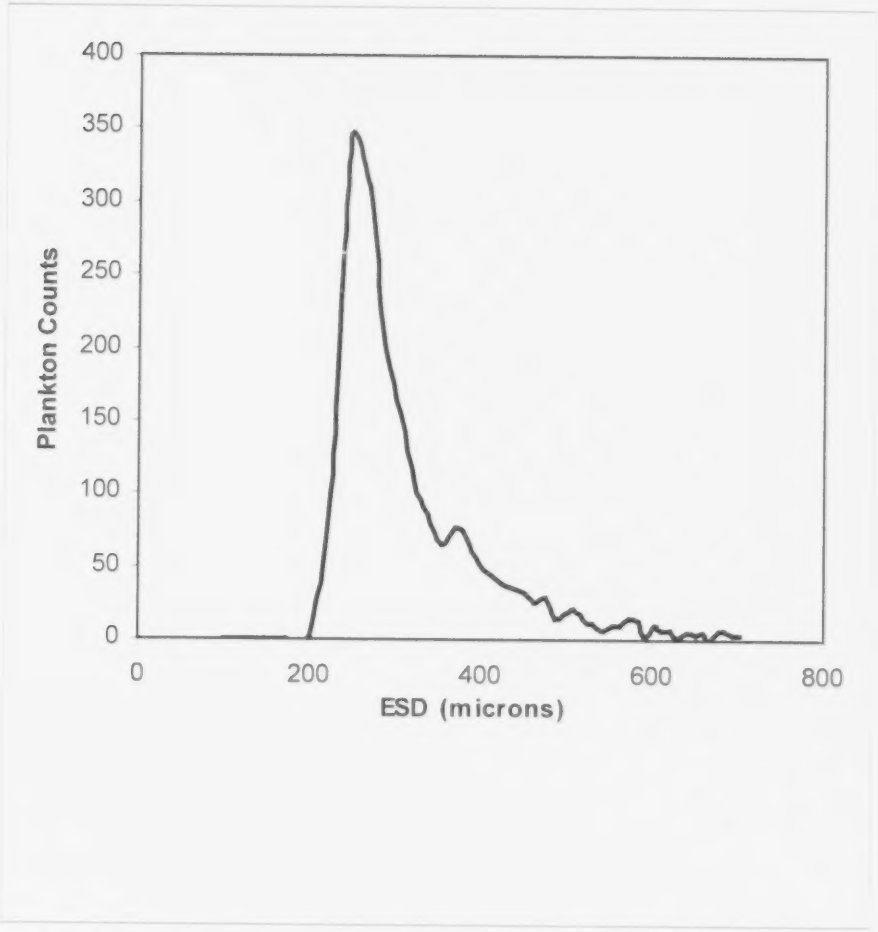


Fig. 1. A typical size distribution measured by the OPC showing the highest counts located in the size range 200-500 μm (ESD units)

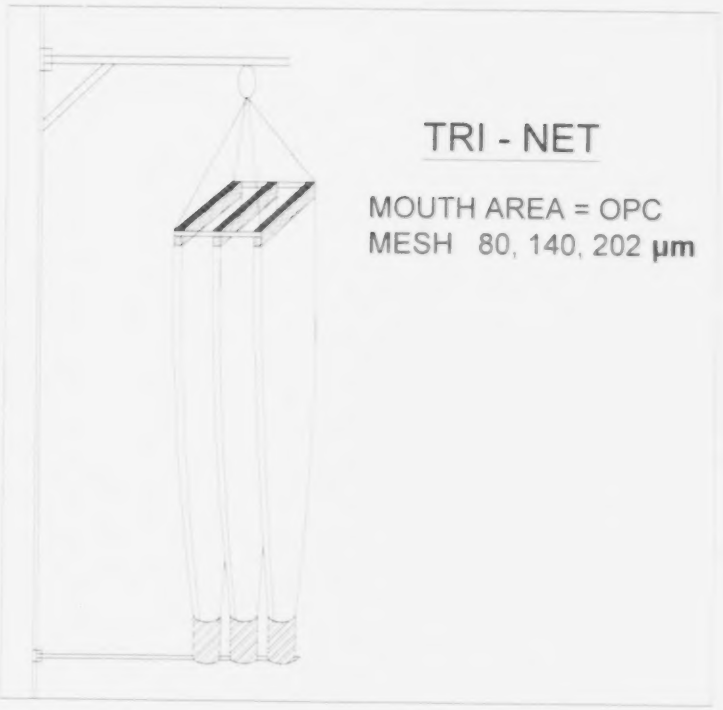


Fig. 2. The Tri-net system showing the 3 nets of differing mesh sizes. The configuration should allow simultaneous sampling of similar plankton distributions.

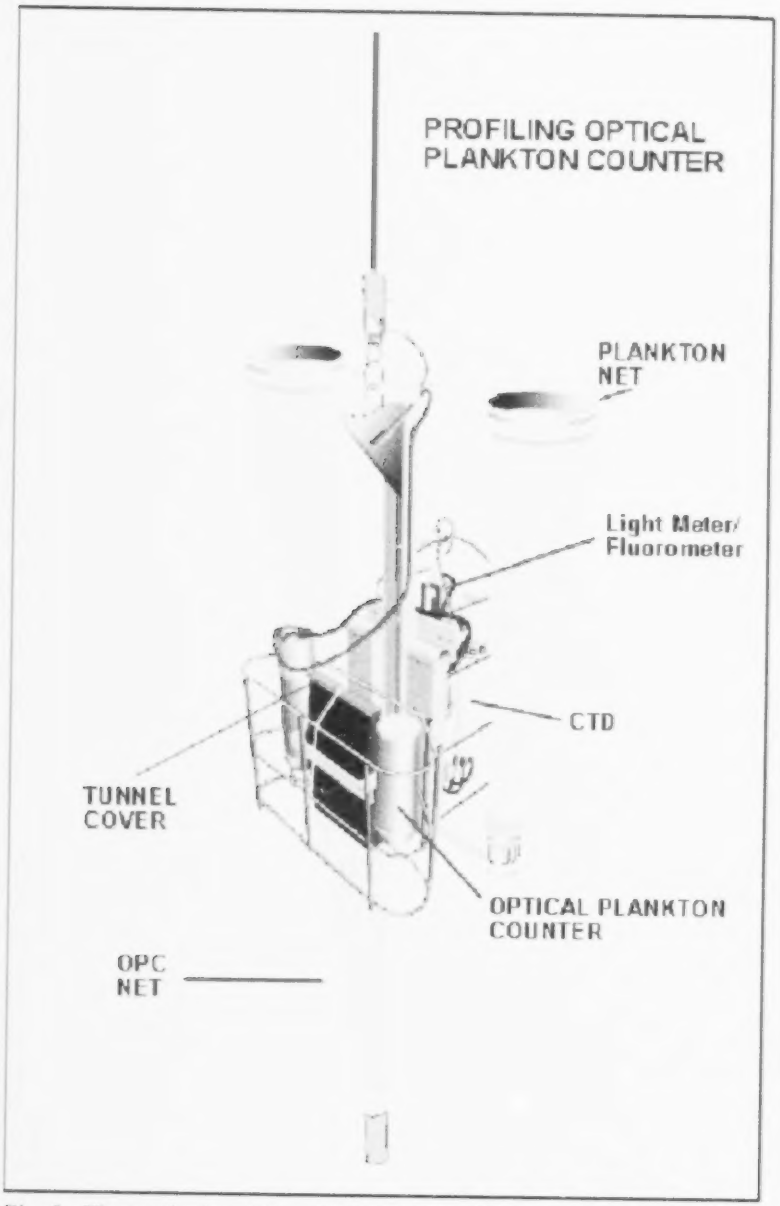


Fig. 3. The vertical profiling OPC (VOPC) with its additional complement of sensors including CTD, fluorometer, light meter and bongo nets with 20 cm mouth diameter. A net is attached to the outflow of the OPC while a cover blocks the OPC mouth and is released just before ascent.

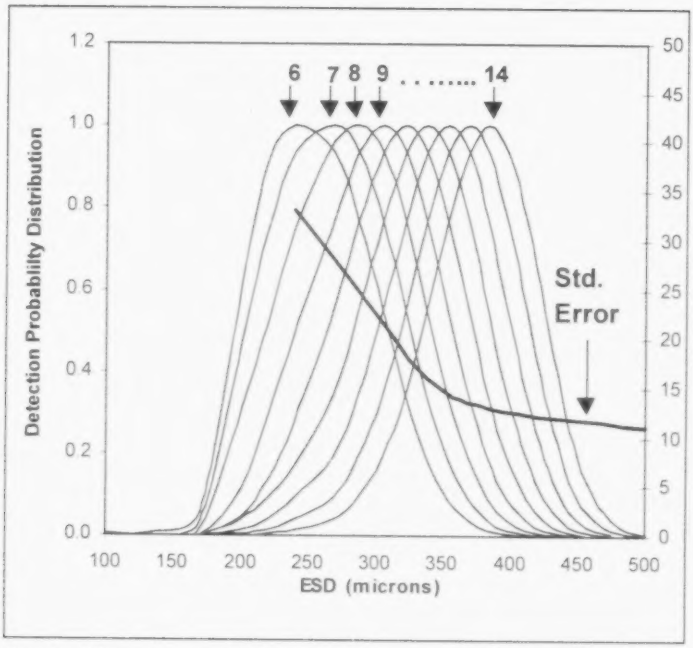


Fig. 4. The measured OPC detection probability distribution as a function of size (ESD). The percentage std. error is largest at the smallest sizes.

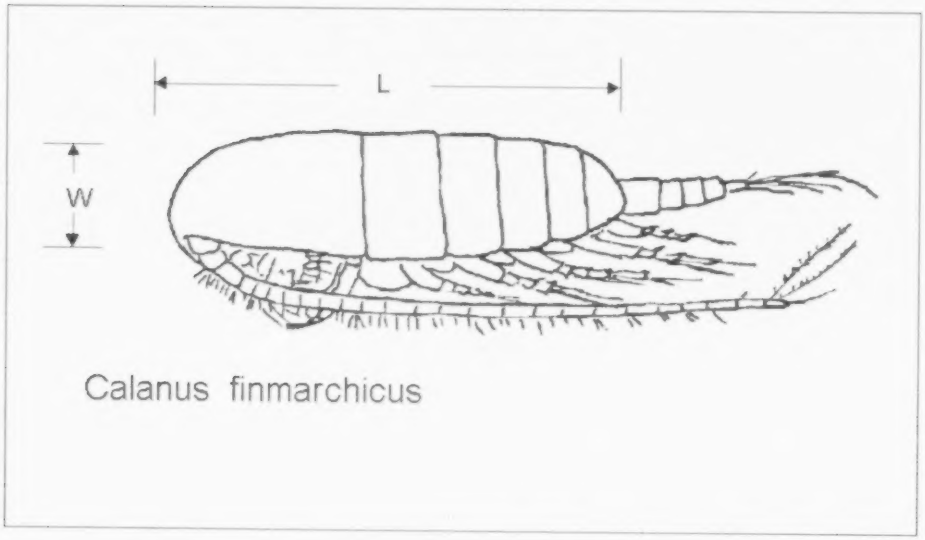


Fig. 5. The typical shape outline of the copepod *Calanus finmarchicus* and its appendages.

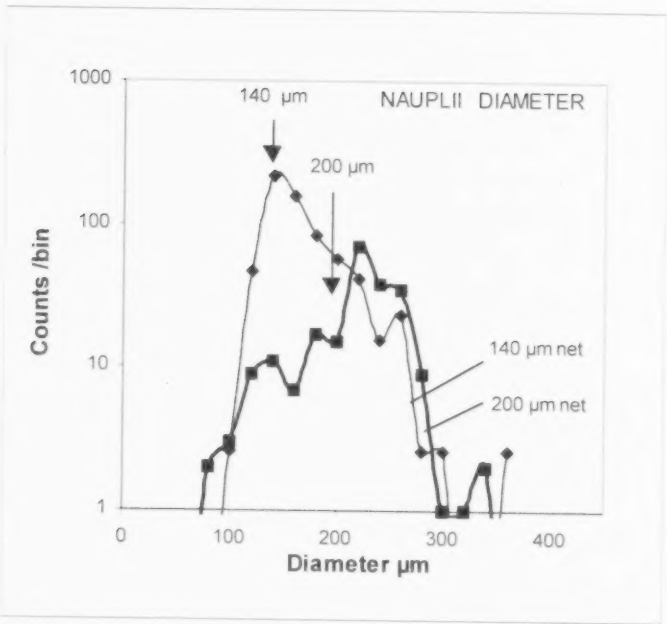


Fig. 6. The width or diameter distributions of nauplii sampled in the 140 & 202 µm nets.

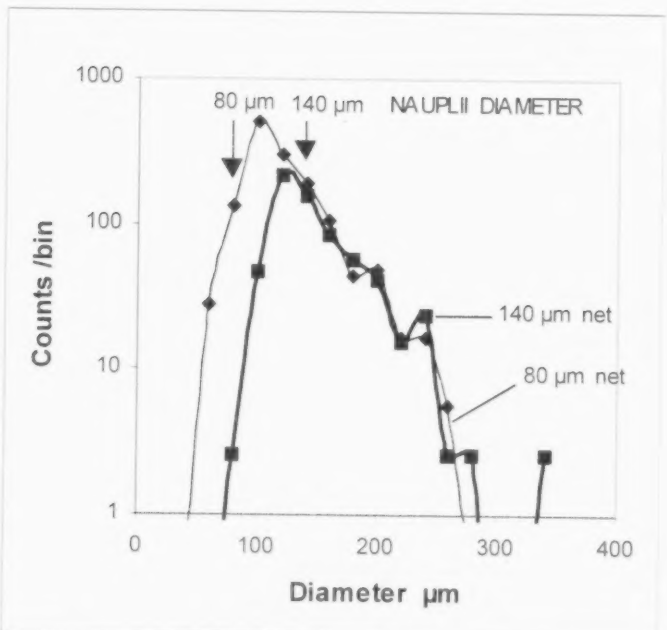


Fig. 7. The width or diameter distributions of nauplii sampled in the 80 and 140 µm nets.

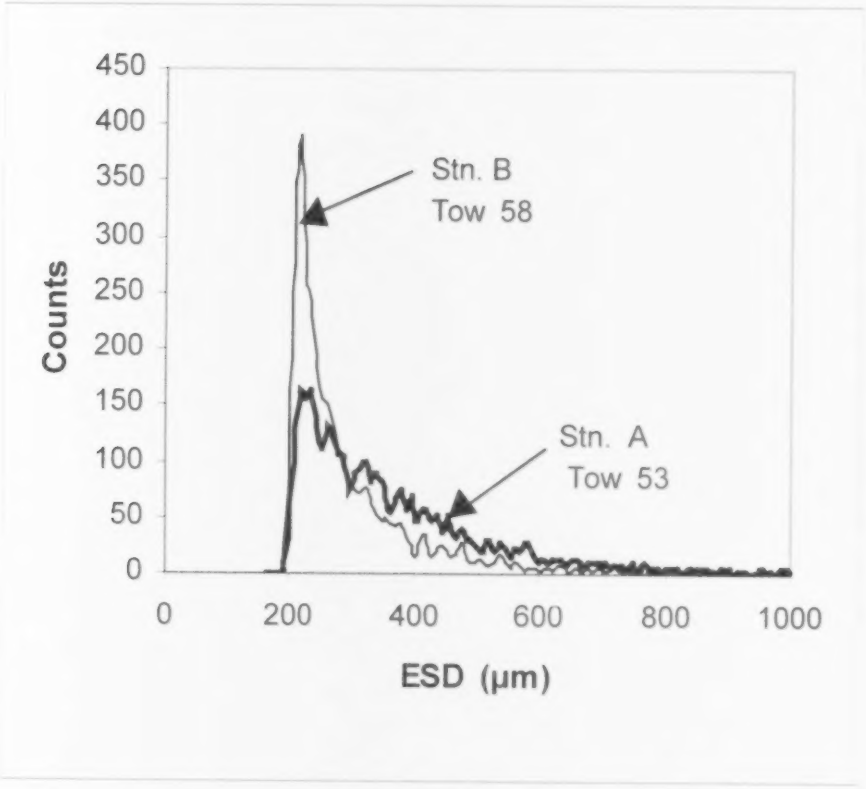
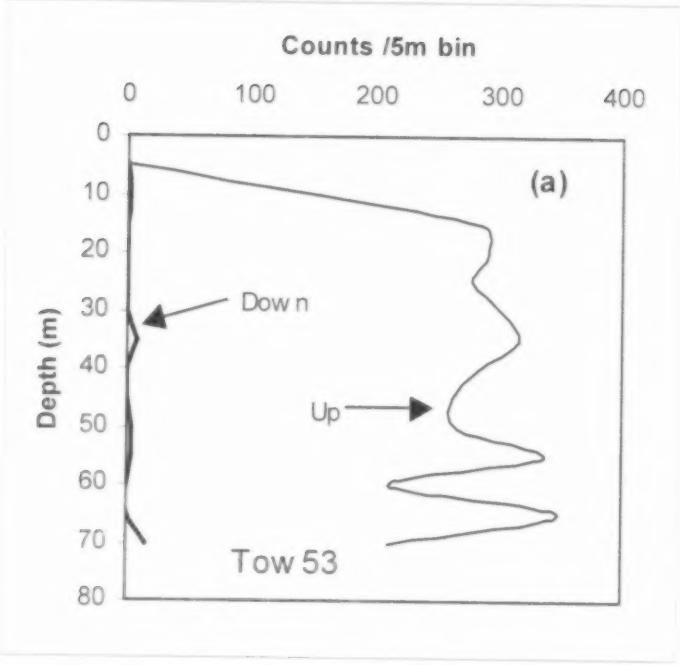
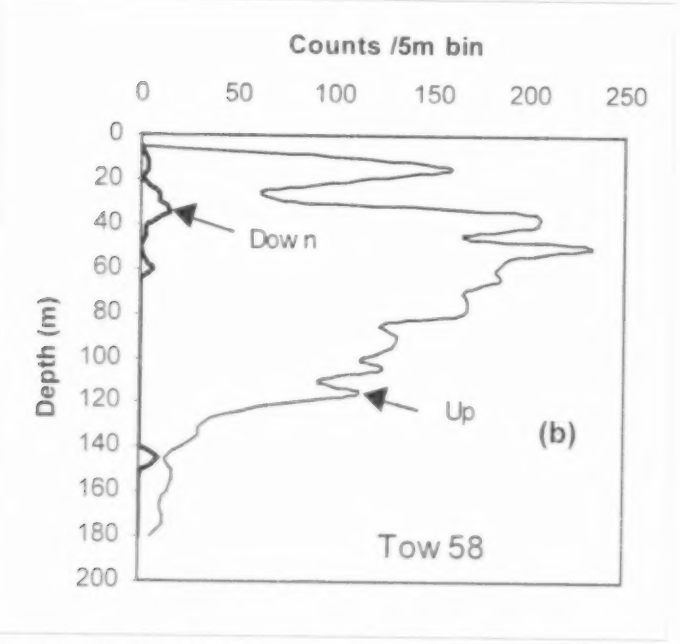


Fig. 8. The OPC measured size distributions for Stn. 53 & 58 showing the density differences.





Figs. 9(a,b). The OPC measured profile of plankton counts for Stns. 53 & 58. The descent shows minimal counts as a result of the cover on the OPC tunnel mouth.

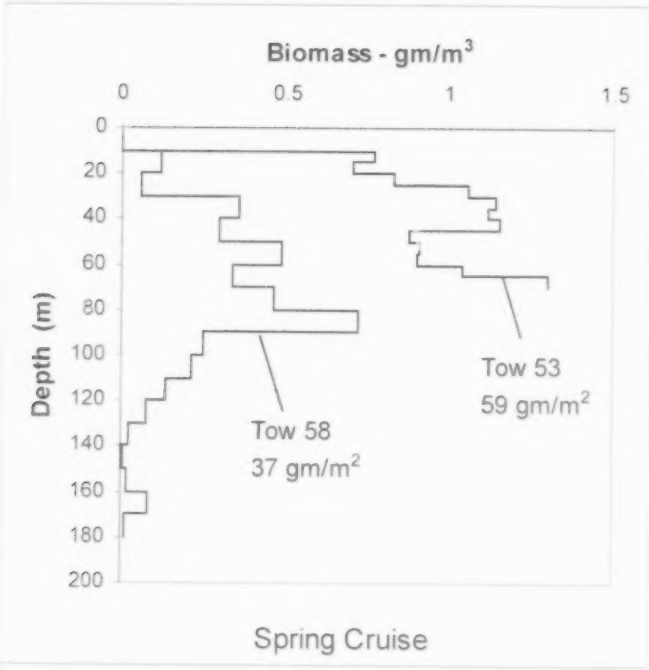


Fig. 10. The OPC measured biomass density profile corresponding to Fig.s 9(a,b).

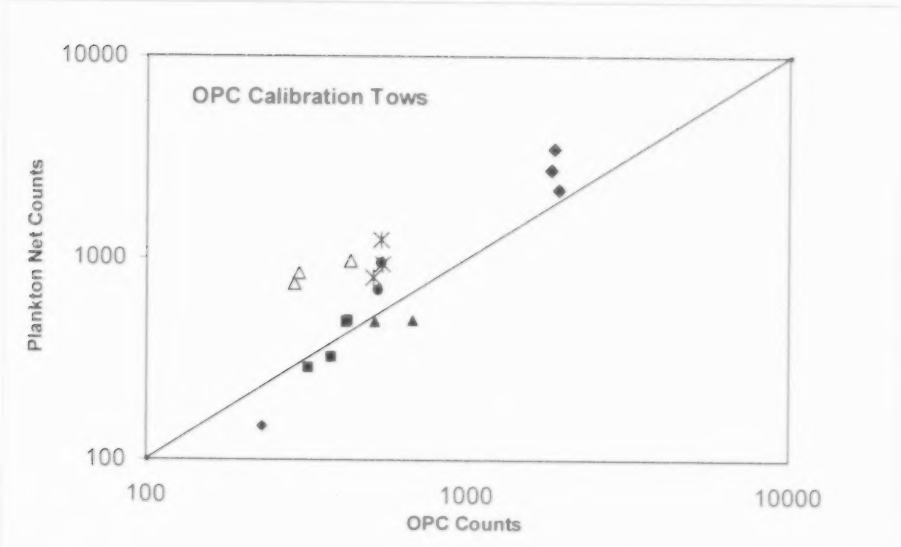


Fig. 11. Plankton counts from the OPC outflow net as compared to OPC measured counts for 7 stations during the fall cruise.

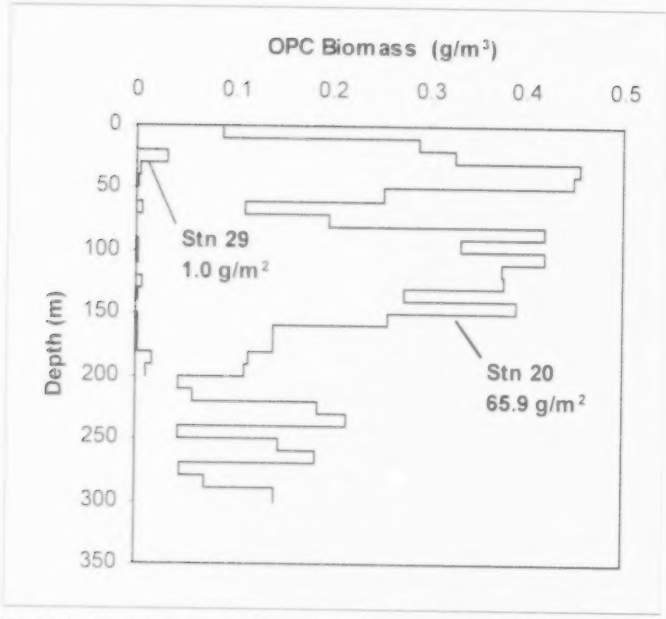


Fig. 12. Biomass profiles measured by the OPC for 2 stations during the fall cruise illustrating the extreme ranges encountered.

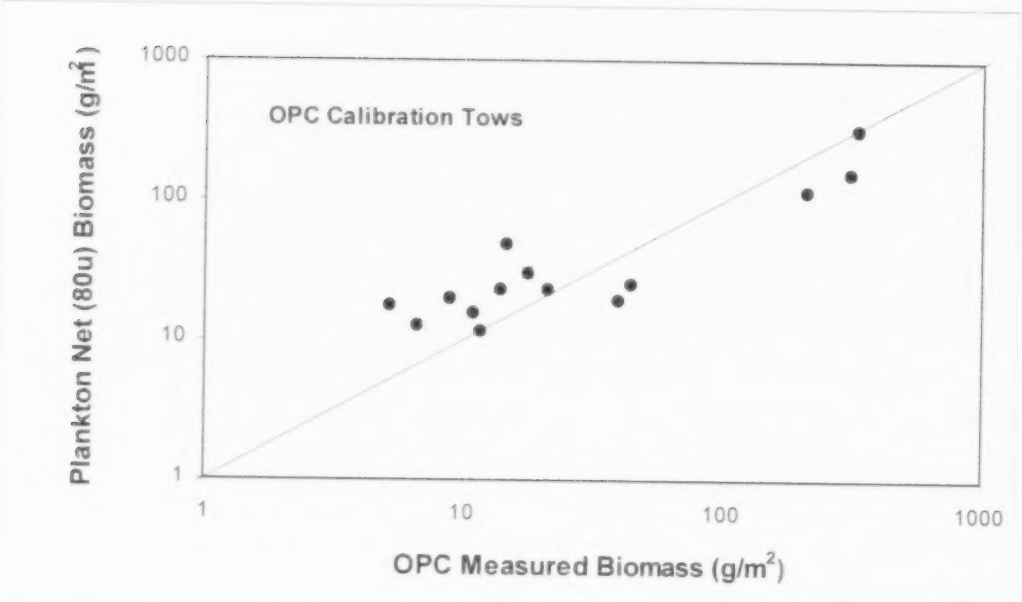
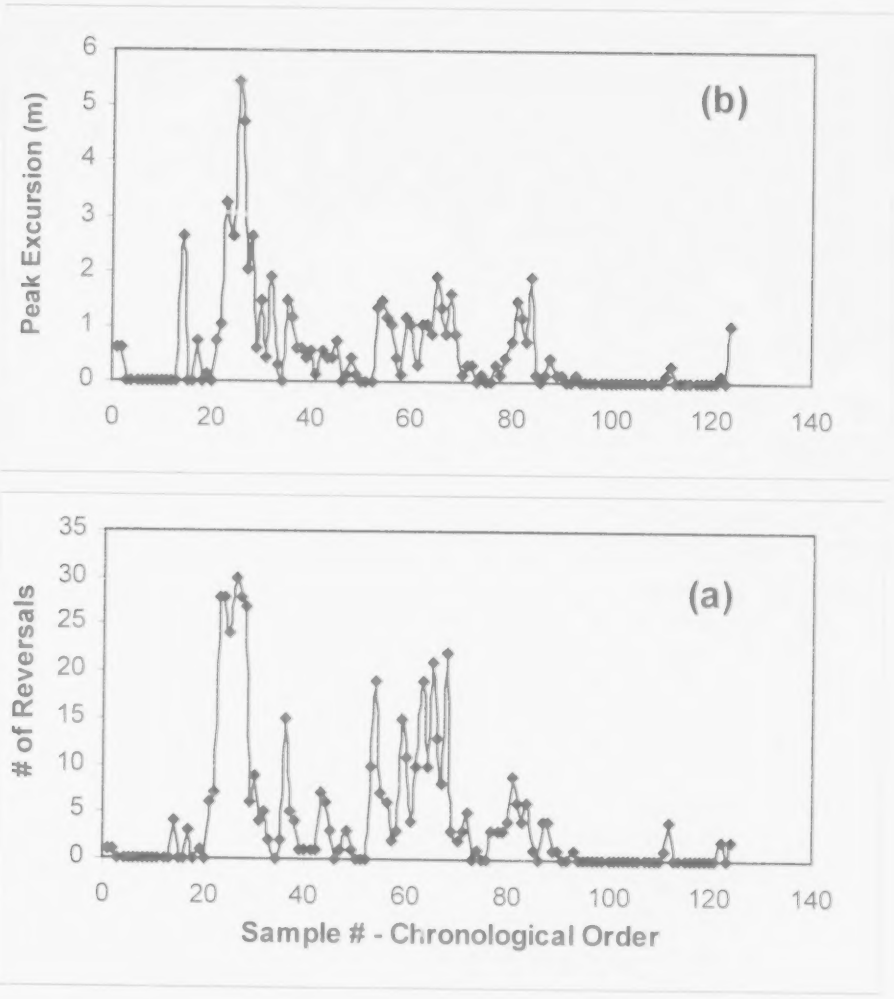
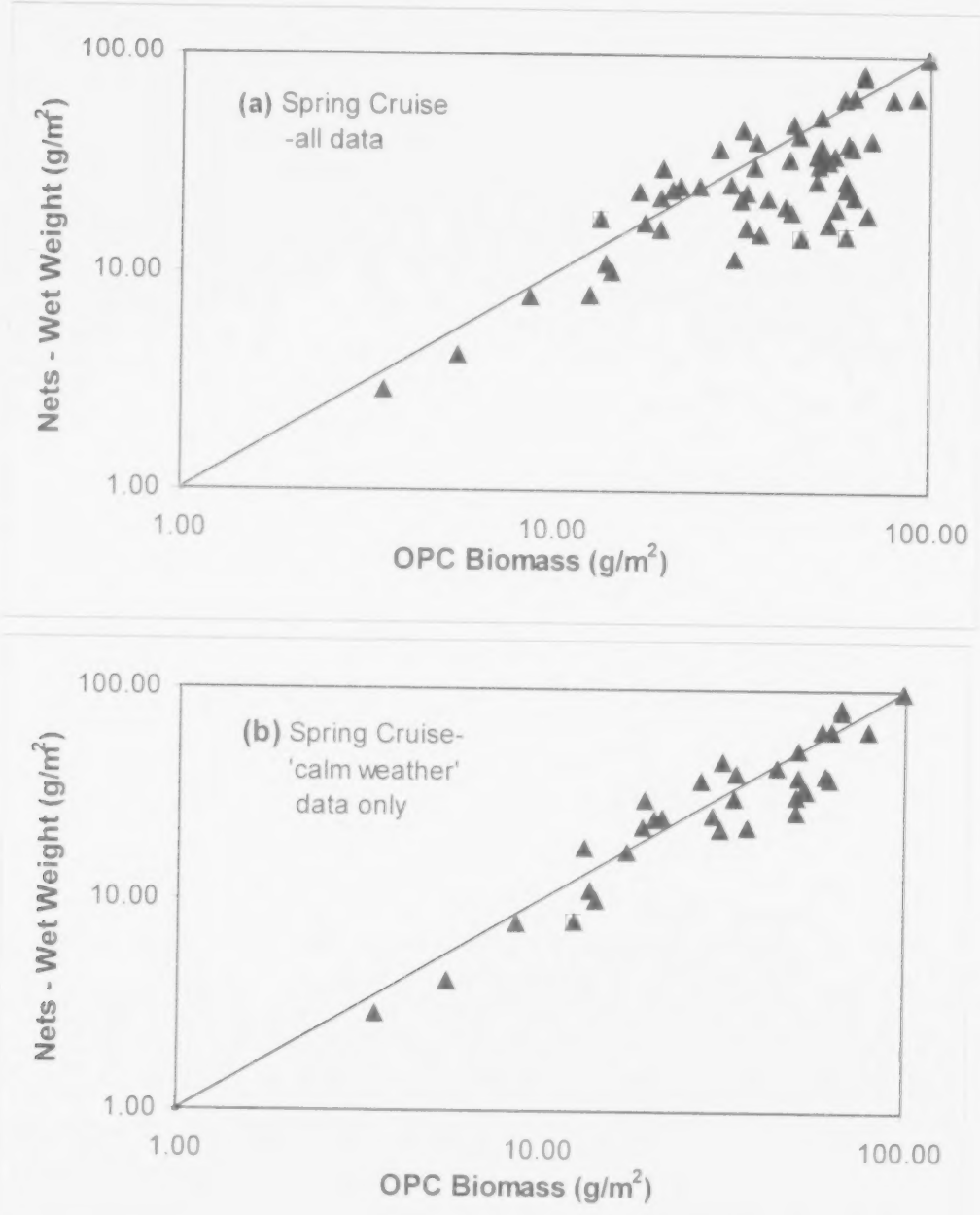


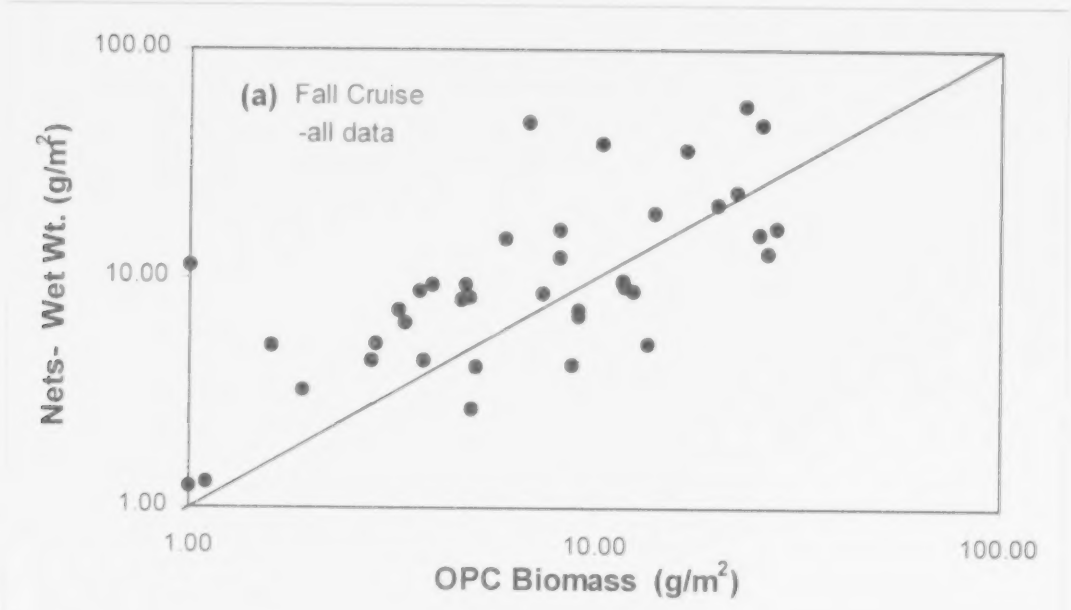
Fig. 13. Integrated biomass (g/m^2) for the OPC calibration tows where the net sample from the OPC outflow was weighed and compared to the OPC measured biomass.

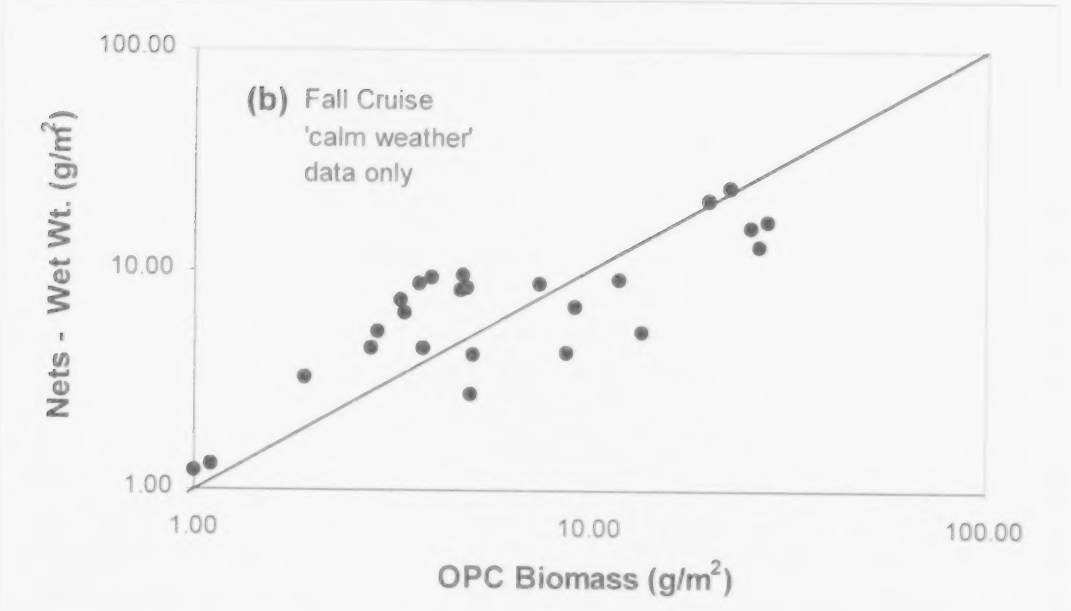


Figs. 14(a,b). Peak excursions (a), that is, the maximum distance the net would reverse direction during ascent and (b) the number of times the net would reverse during any one profile plotted as a function of sample number (in chronological order).



Figs. 15(a.b). Measurements of VOPC net sampled biomass plotted against the OPC measured biomass for all stations (a) during the spring cruise and (b) filtering out those stations where reversals were >0.5 m.





Figs. 16(a.b). Measurements of VOPC net sampled biomass plotted against the OPC measured biomass for all stations (a) during the fall cruise and (b) filtering out those stations where reversals were >0.5 m.

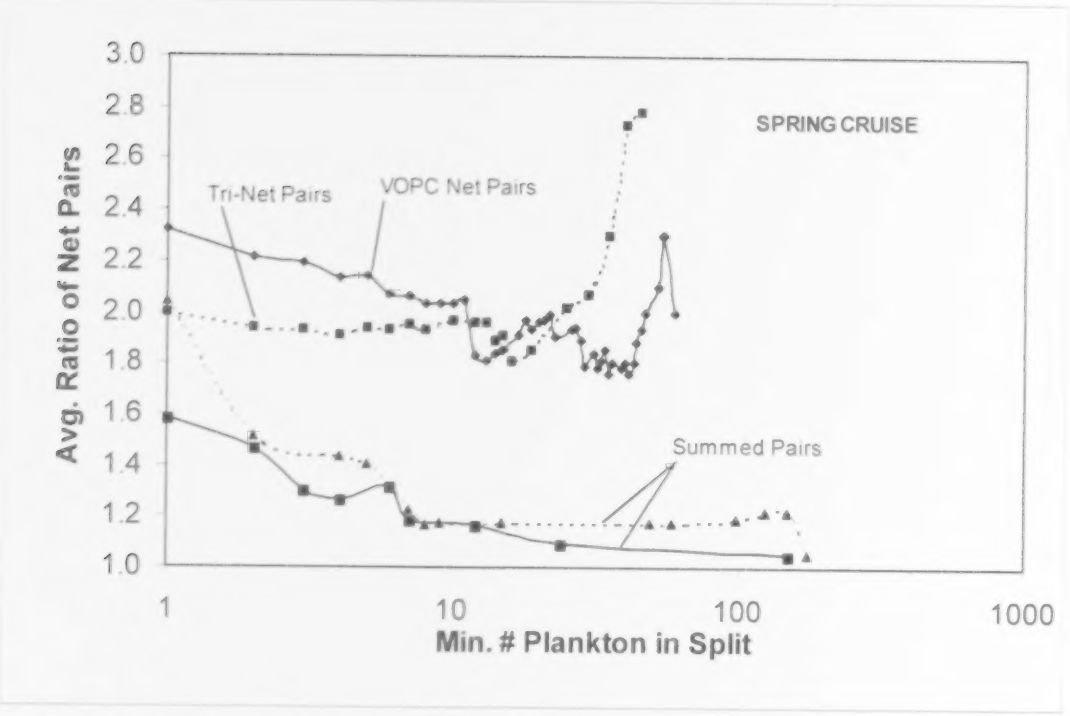


Fig. 17. The mean ratio of counts from net pairs (VOPC & Tri-Net) plotted against minimum number of plankton in the split, that is, if a minimum limit were set at 5 counts, then must be a minimum of 5 animals of a specific species and stage, i.e. *Cal. fin. II* or *Cal. glacialis IV* in that split for the data to be included. The lower plot 'summed pairs' adds and averages the 7 profiles taken on a single Tri-Net station lasting 1-1/2 hours.